Some of the slides are copied from the course materials of DigiVFX instructed by **Prof. Yung-Yu Chang** at NTU

Matting

CVFX @ NTHU

30 April 2015

Three papers and some updates

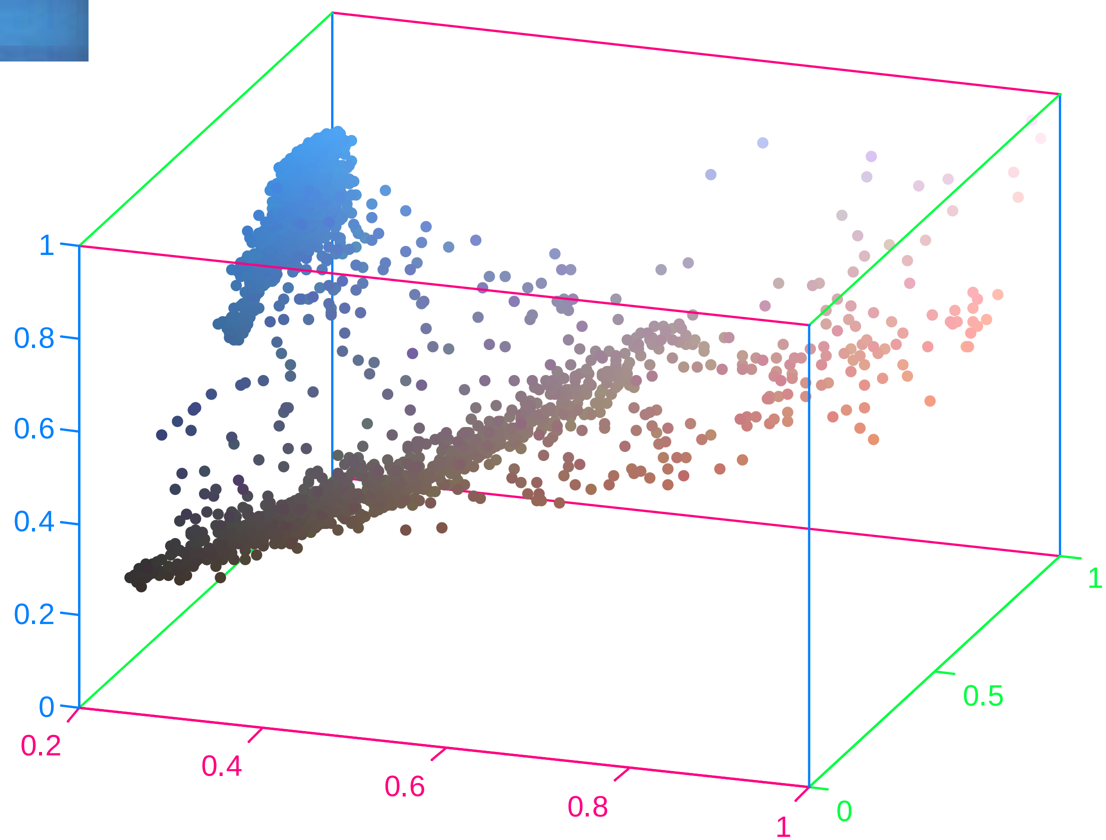
- *A Bayesian Approach to Digital Matting*
  - Yung-Yu Chuang, Brian Curless, David Salesin, and Richard Szeliski
  - CVPR 2001
- *Flash Matting*
  - Jian Sun, Yin Li, Sing Bing Kang, and Harry Shum
  - SIGGRAPH 2006
- *A Closed Form Solution to Natural Image Matting*
  - Levin, Lischinski, and Weiss
  - CVPR 2006

Chroma Keying

wikipedia

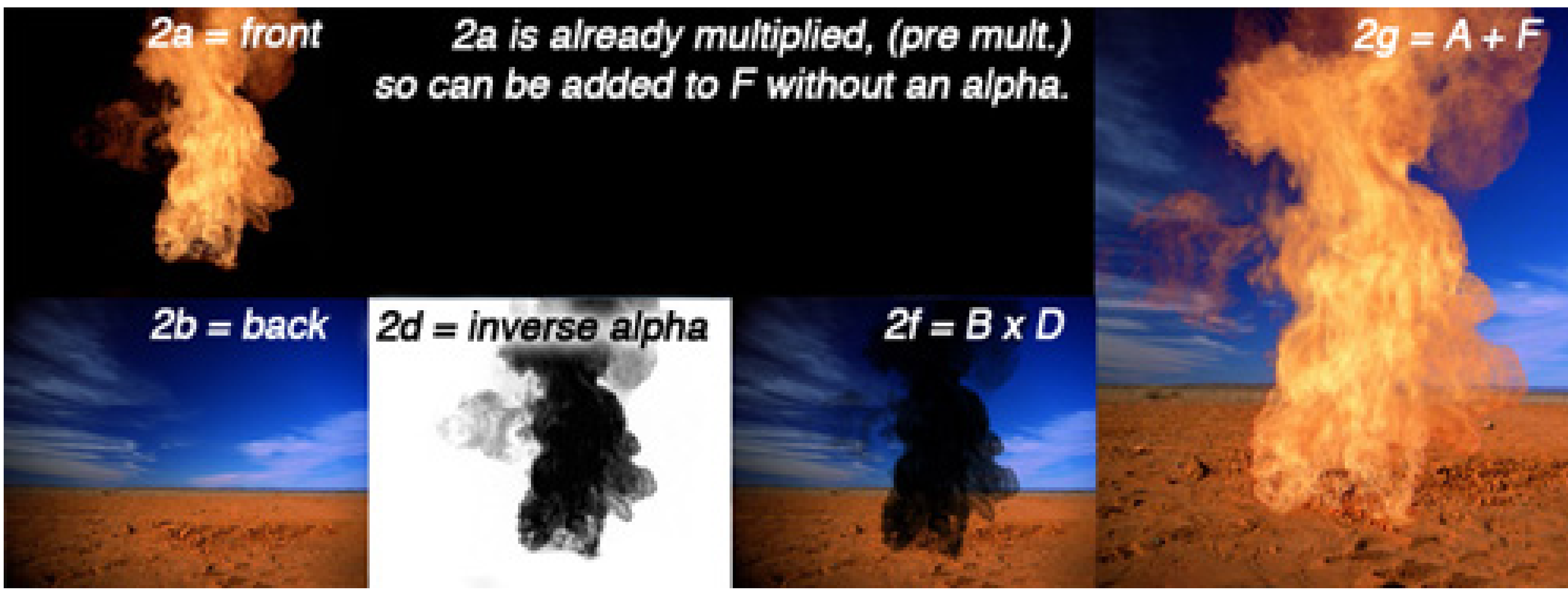





1
0.8
0.6
0.4
0.2
0
0.2
0.4
0.6
0.8
1
0
0.5
1

Examples

http://grail.cs.washington.edu/projects/digital-matting/image-matting/



http://www.fxguide.com/fxtips-242.html

Compositing Equation

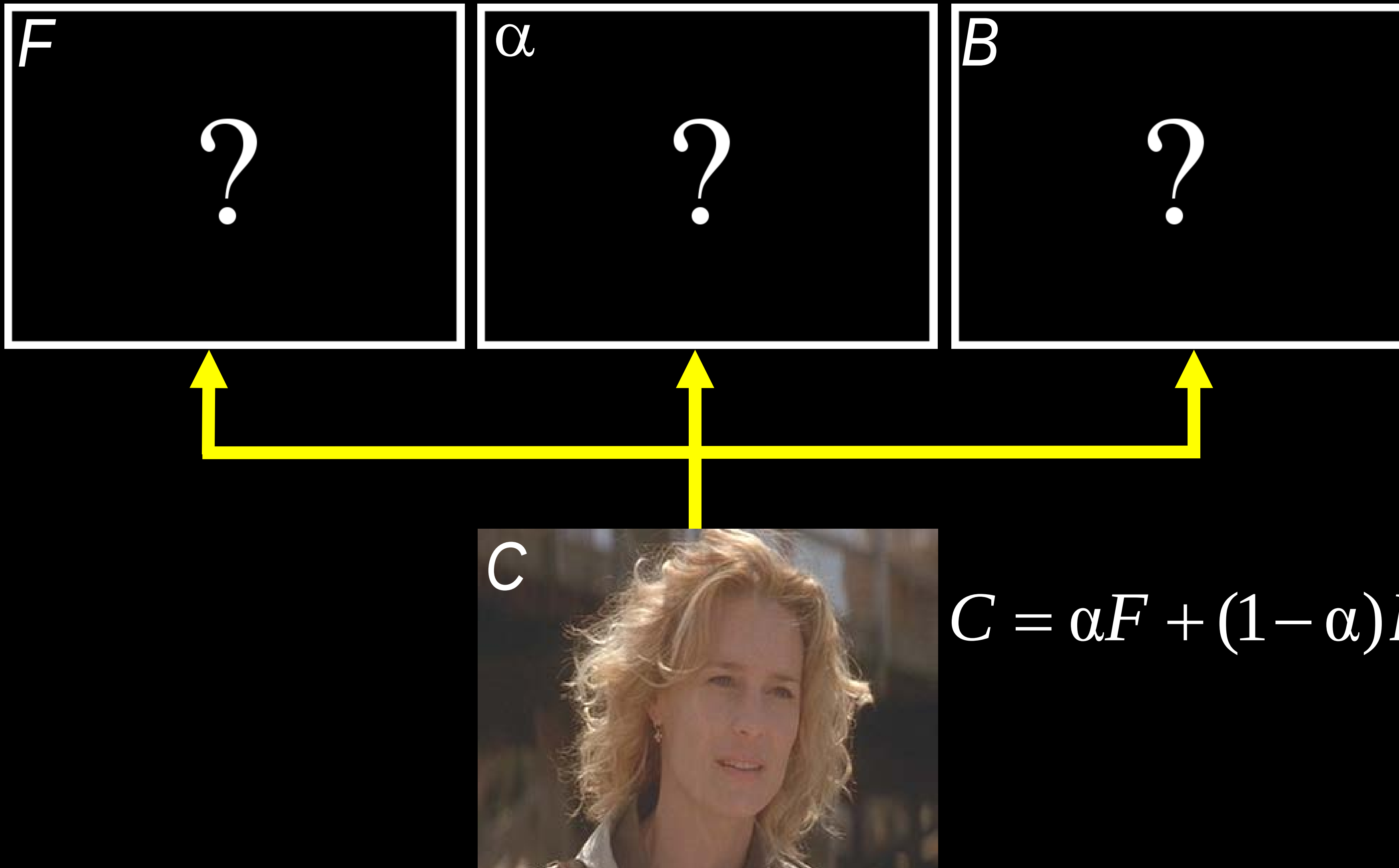
$$C = \alpha F + (1 - \alpha) B$$

composite foreground background

alpha channel

digital matting:

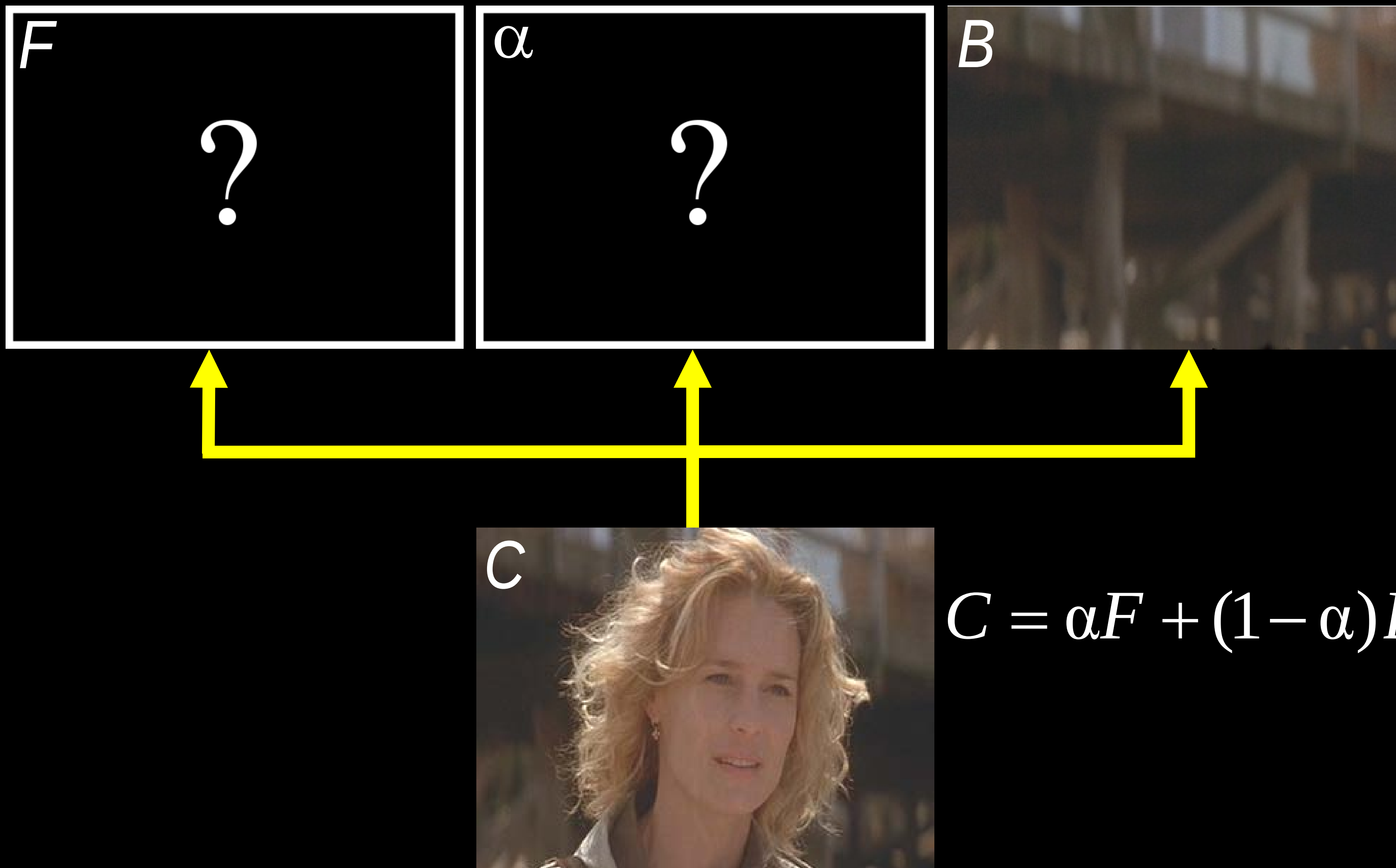
α, F, and B are unknowns



$$C = \alpha F + (1 - \alpha) B$$

Matting (reduce #unknowns)

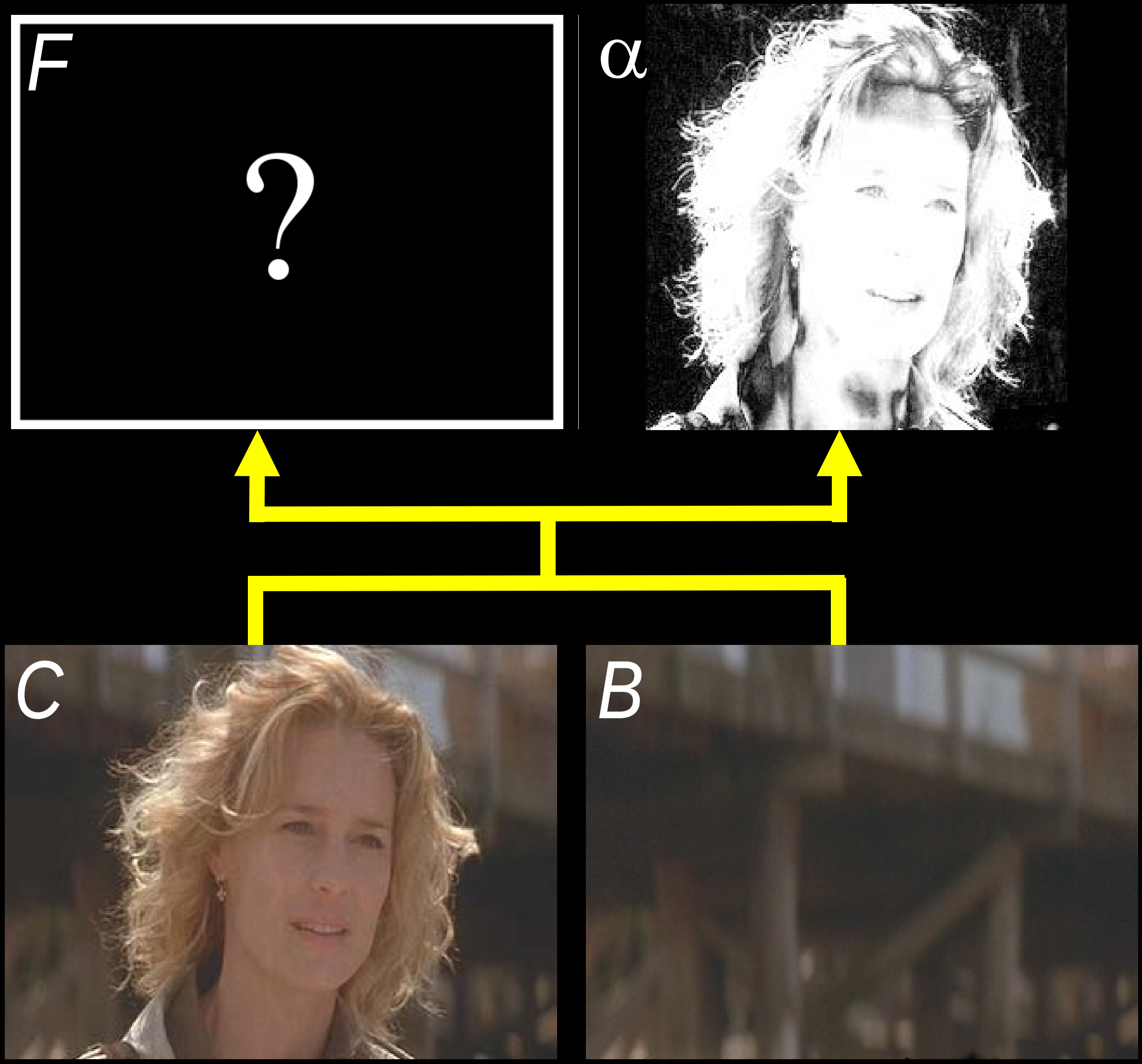
slides by Chuang *et al.*



$$C = \alpha F + (1 - \alpha) B$$

Matting (reduce #unknowns)

slides by Chuang *et al.*

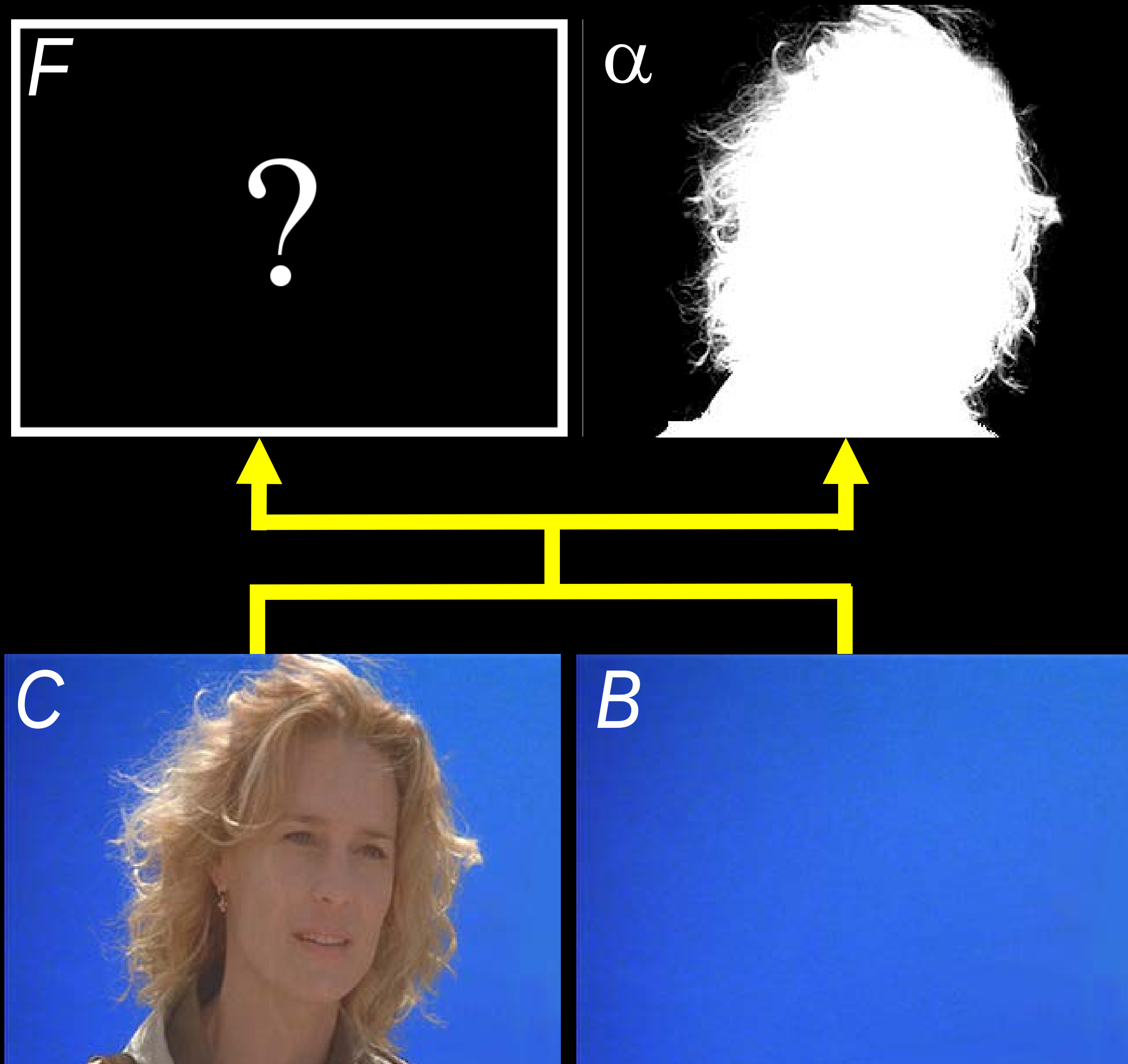


$$C = \alpha F + (1 - \alpha) B$$

difference matting

Matting (reduce #unknowns)

slides by Chuang *et al.*

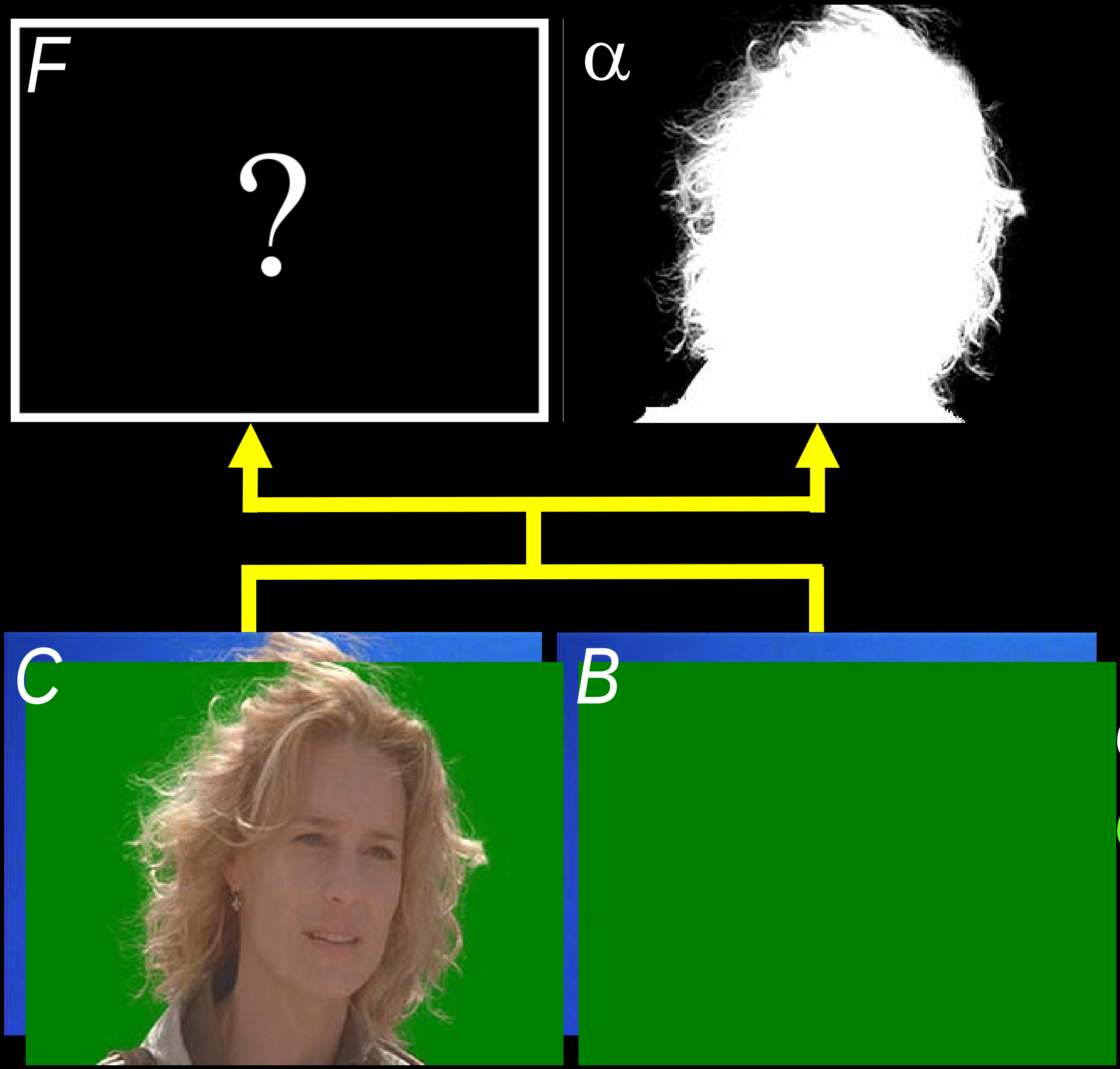


$$C = \alpha F + (1 - \alpha) B$$

blue screen matting

Matting (reduce #unknowns)

slides by Chuang *et al.*

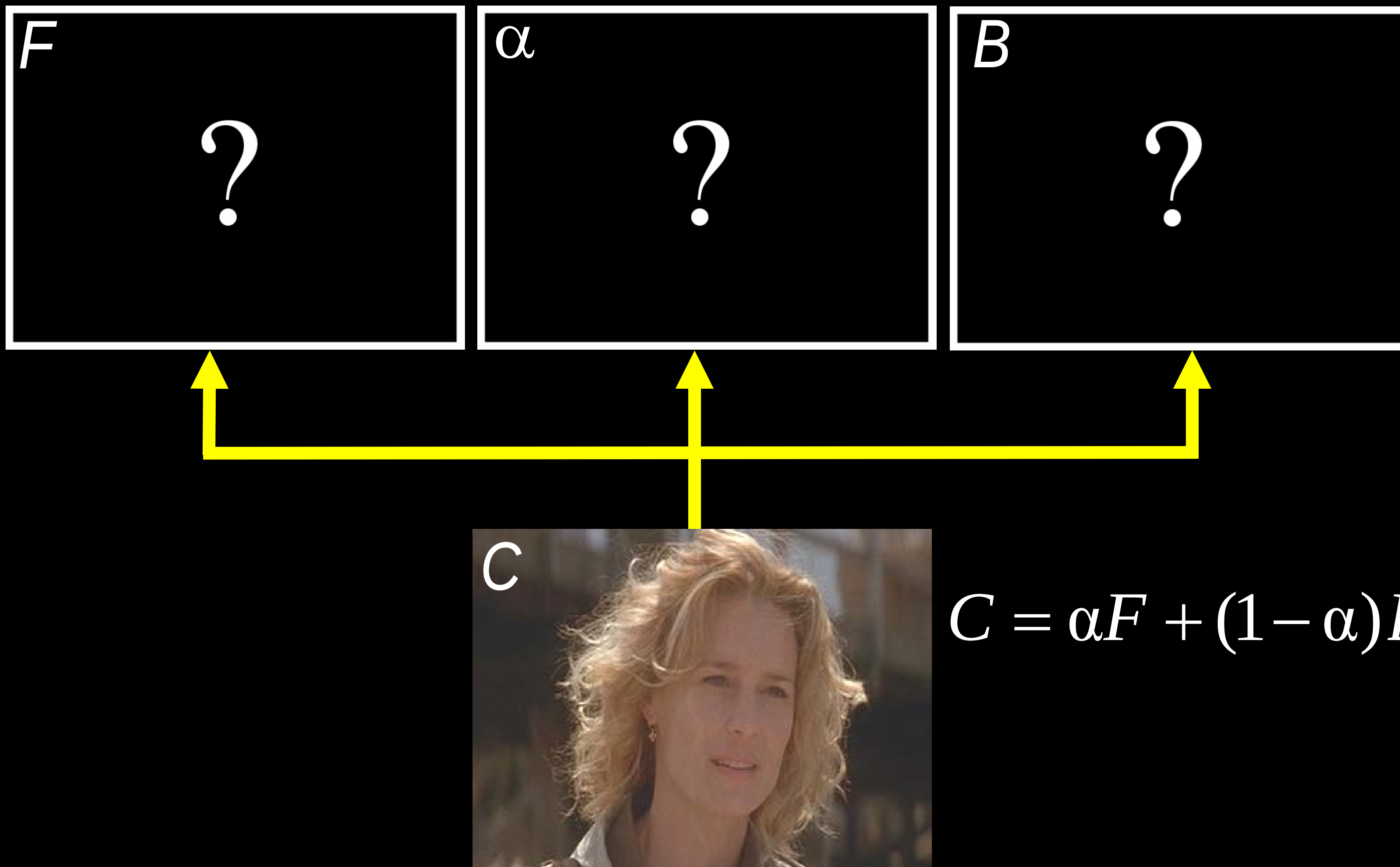


$$C = \alpha F + (1 - \alpha) B$$

$$C = \alpha F + (1 - \alpha) B$$

Matting (add observations)

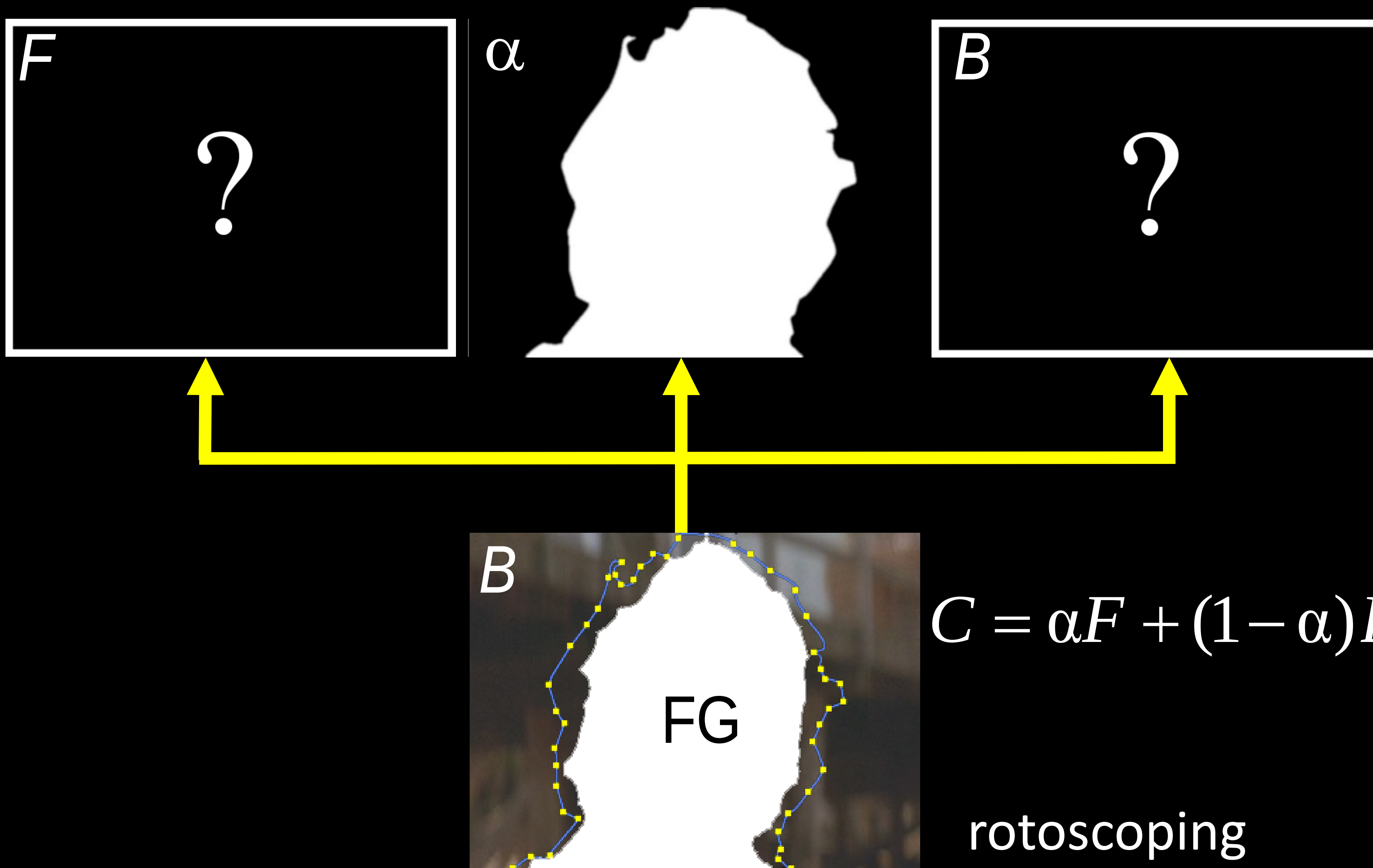
slides by Chuang *et al.*



$$C = \alpha F + (1 - \alpha) B$$

Natural image matting

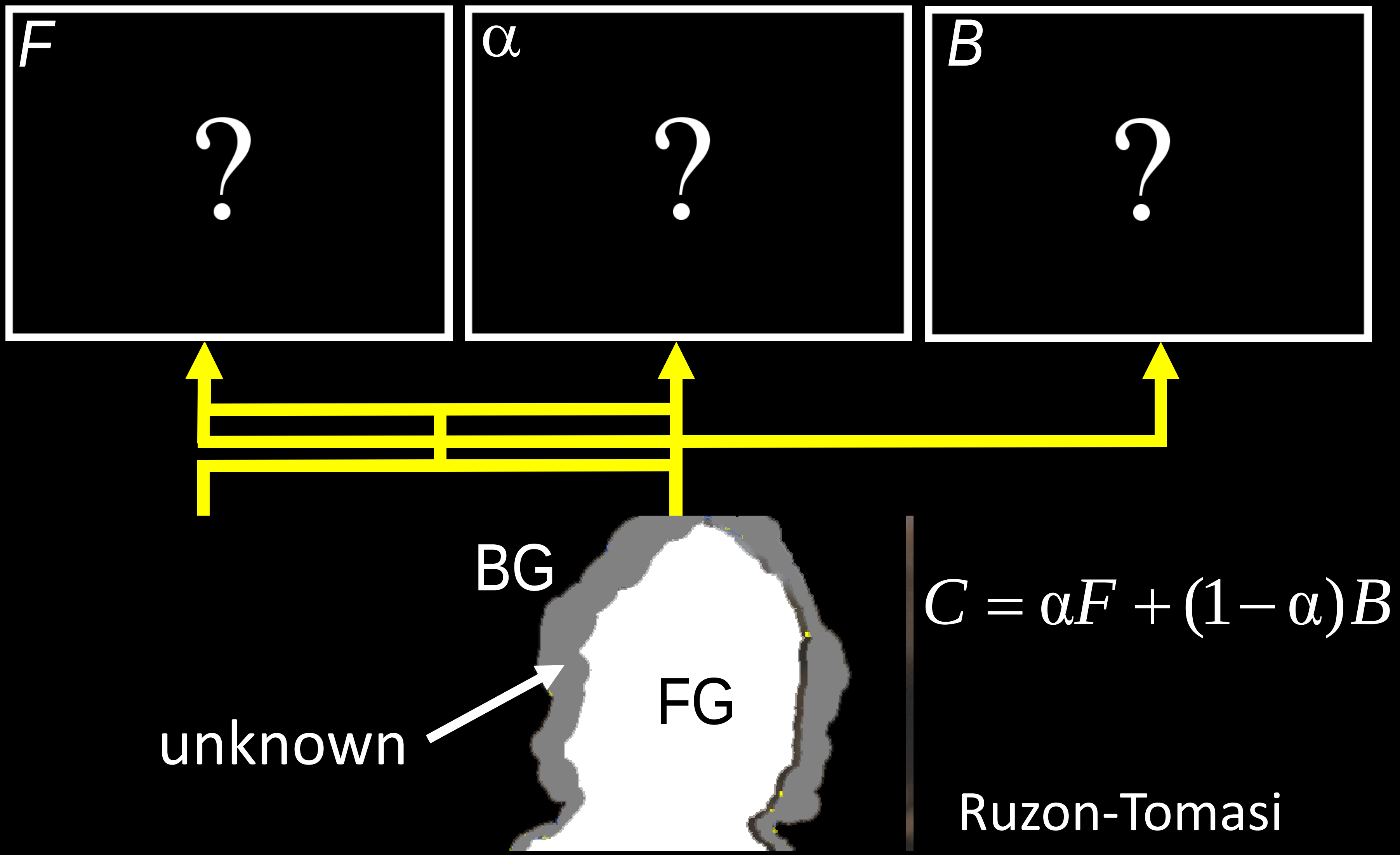
slides by Chuang *et al.*



$$C = \alpha F + (1 - \alpha) B$$

Matting (add priors)

slides by Chuang *et al.*



Matting (add priors)

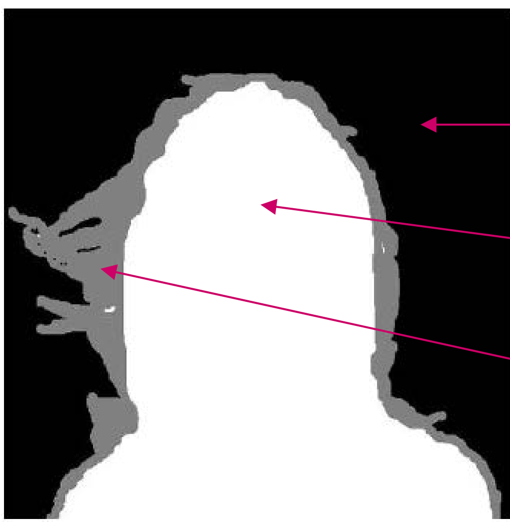
slides by Chuang *et al.*

Another Way to Add Priors

- Draw scribbles

User Segmentation

estimate α, F, and B for all pixels in the unknown region



definite background

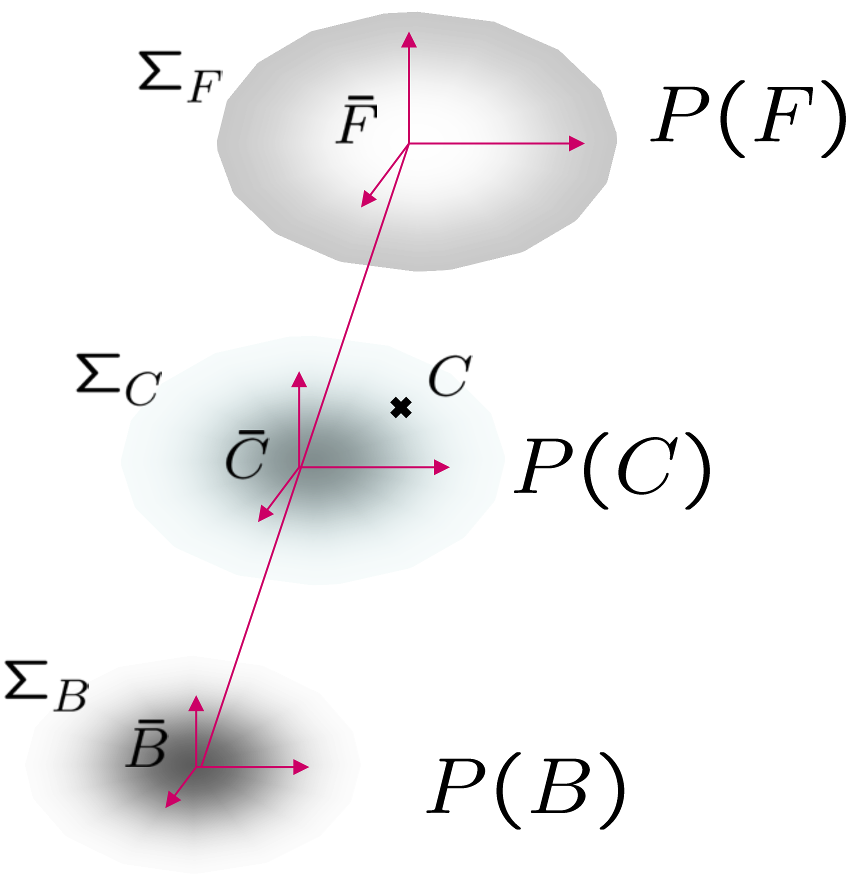
definite foreground

unknown region

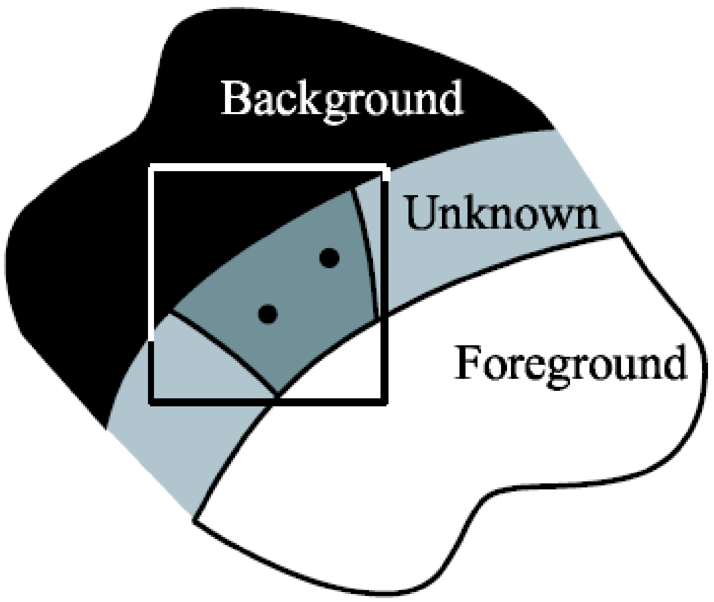
trimap

A Probabilistic View

paired Gaussians

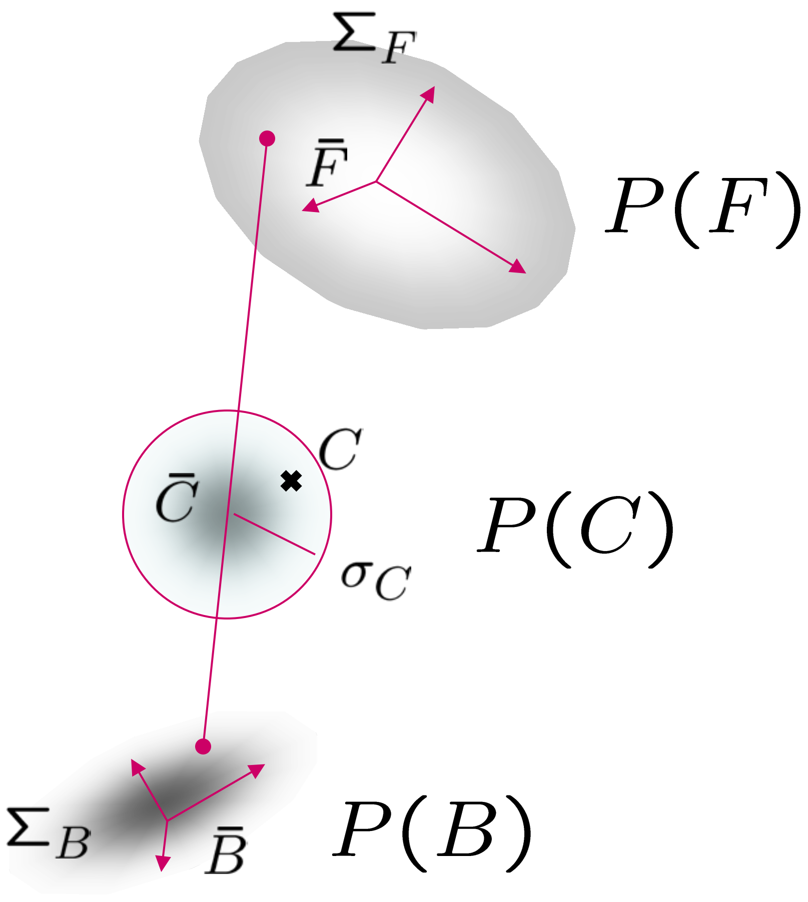


Ruzon-Tomasi

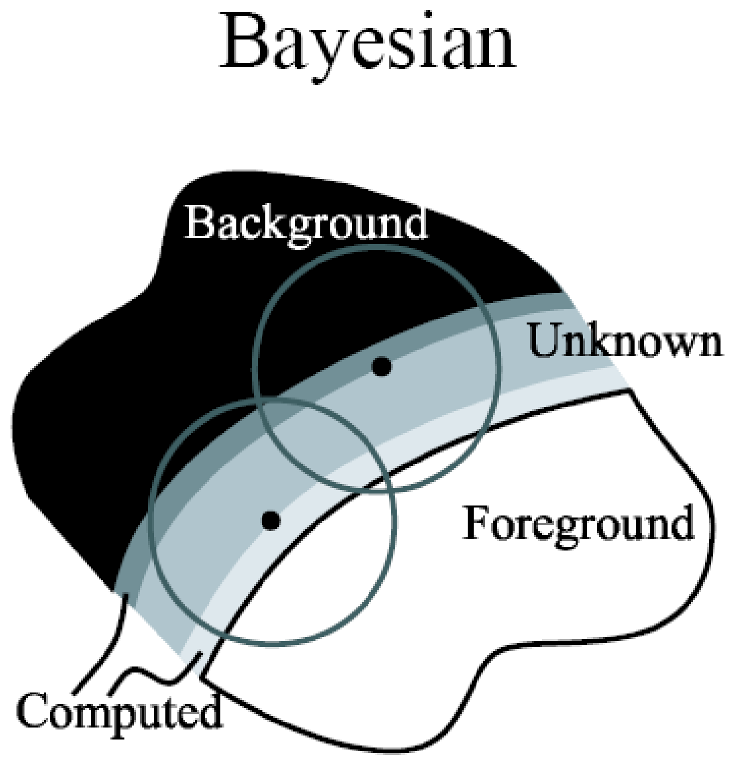


R, G, B colors

Bayesian



Σ_F
$\bar{F}$
$P(F)$
C
$\bar{C}$
σ_C
$P(C)$
Σ_B
$\bar{B}$
$P(B)$



Bayesian
Background
Unknown
Foreground
Computed

Bayesian image matting

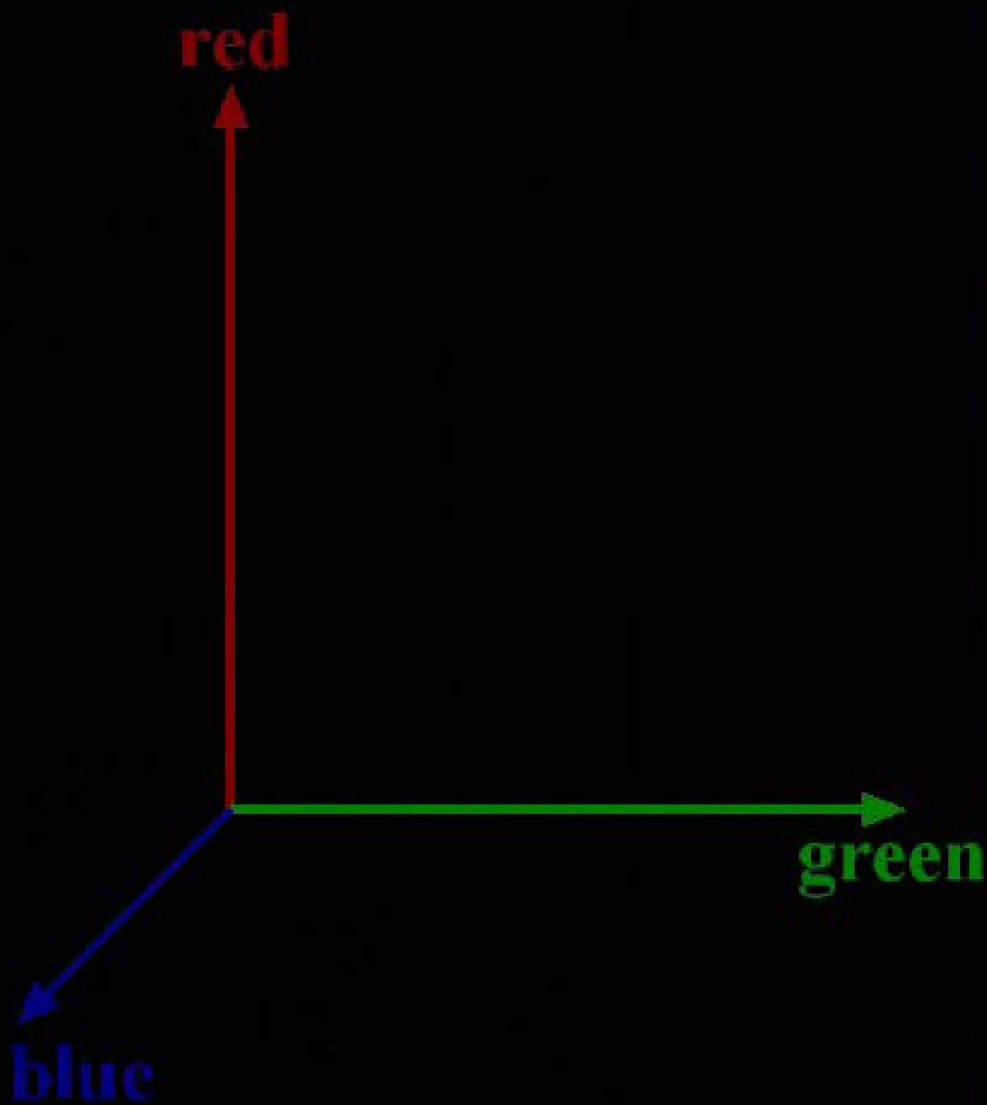
slides by Chuang *et al.*

Bayesian image matting

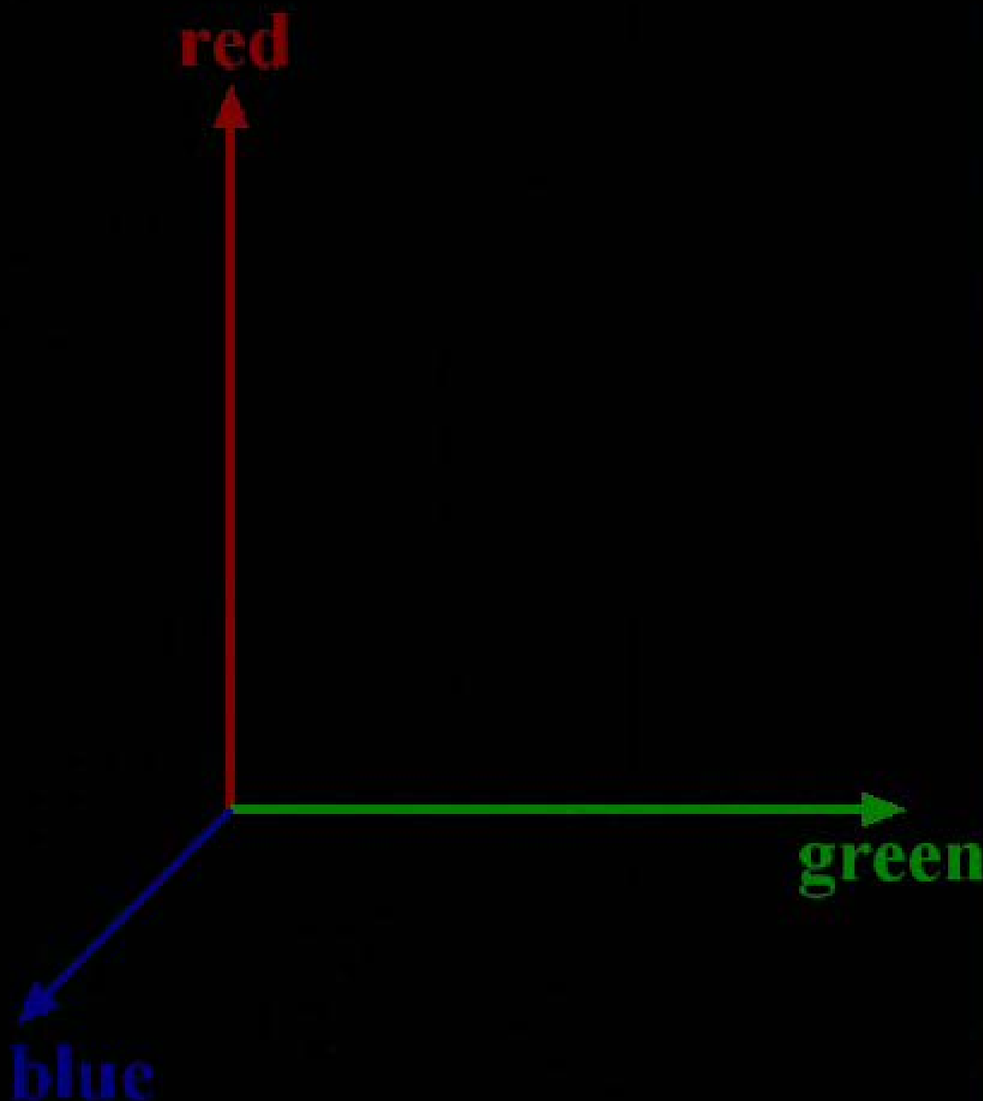
slides by Chuang *et al.*

Bayesian image matting

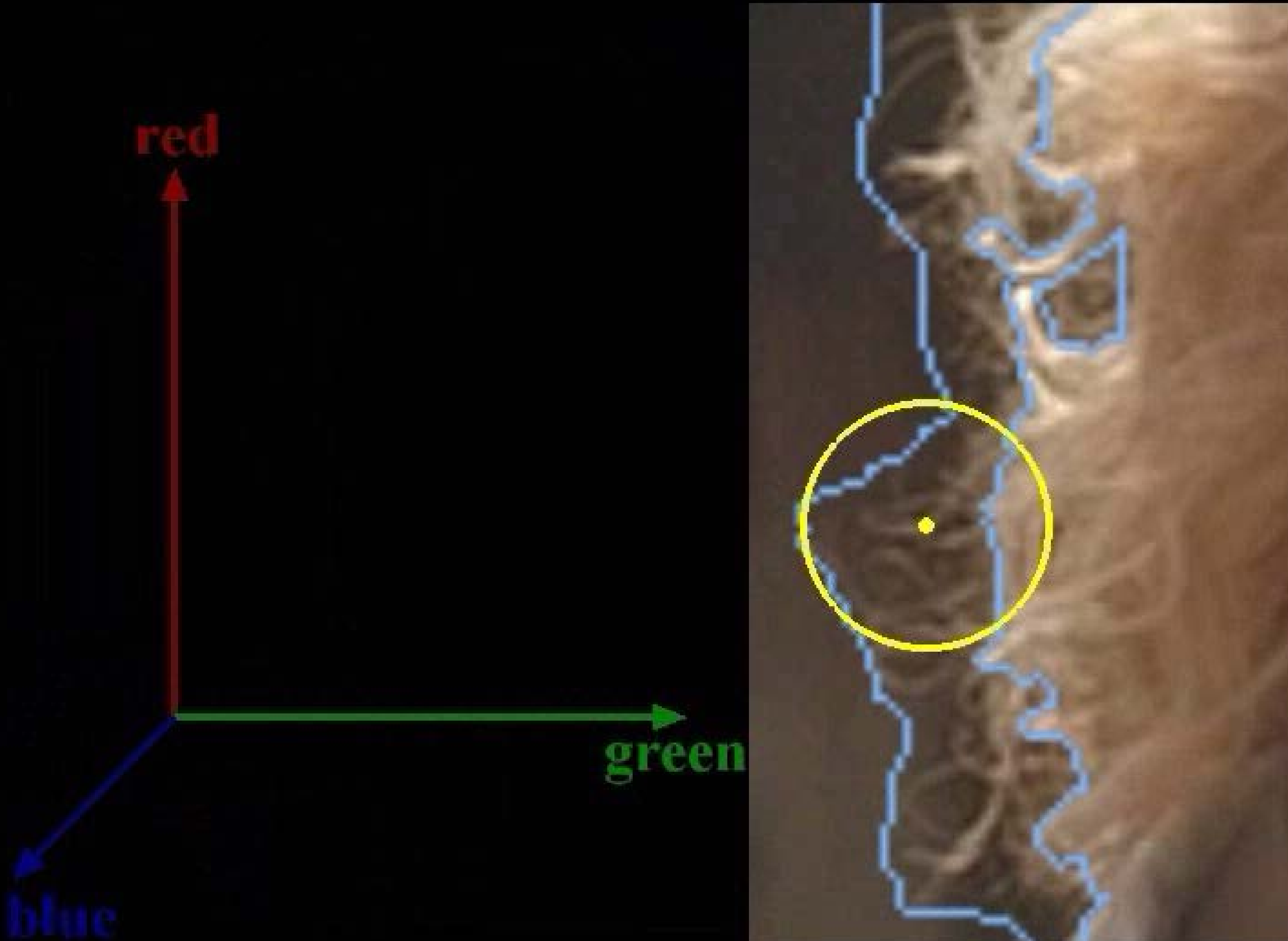
slides by Chuang *et al.*



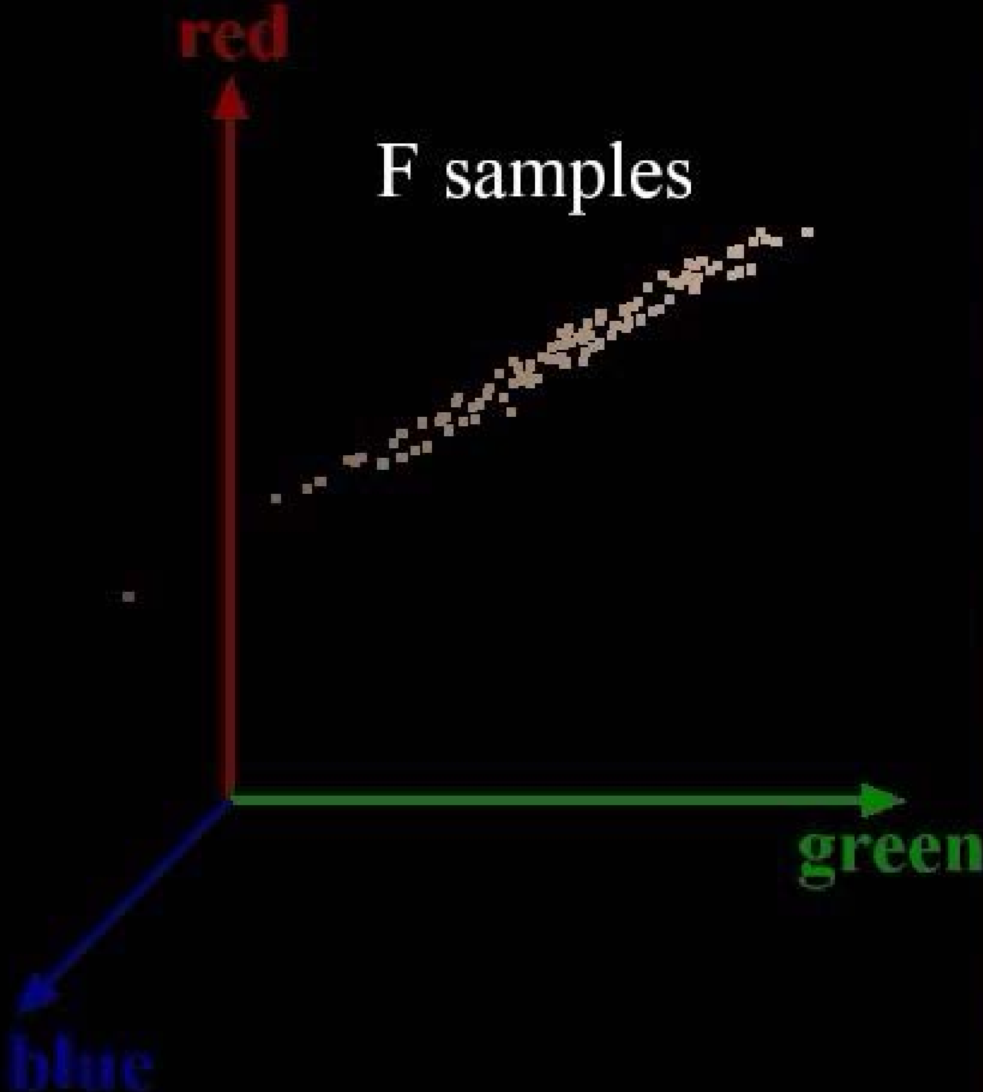
slides by Chuang *et al.*



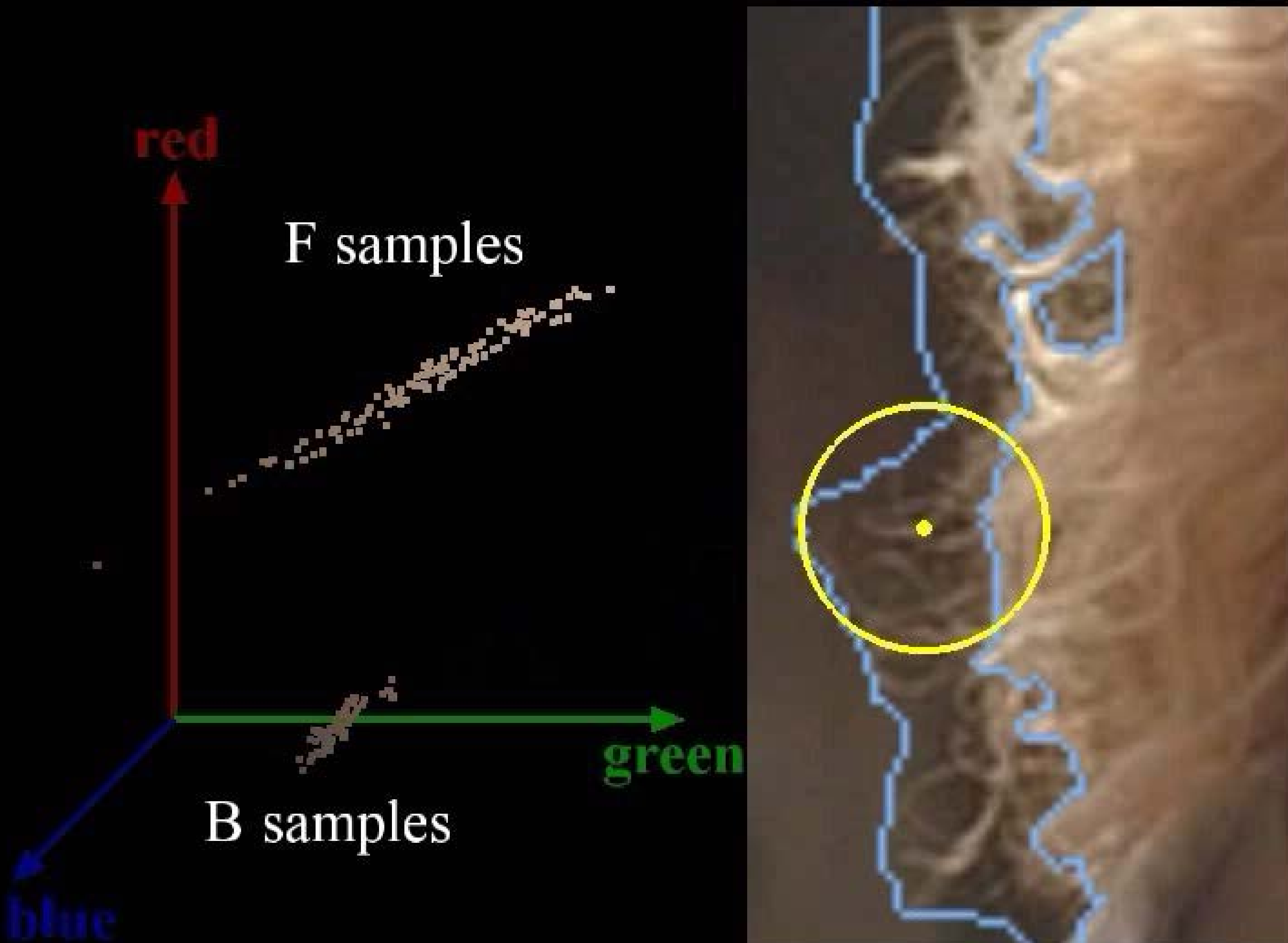
slides by Chuang *et al.*



slides by Chuang *et al.*



slides by Chuang *et al.*



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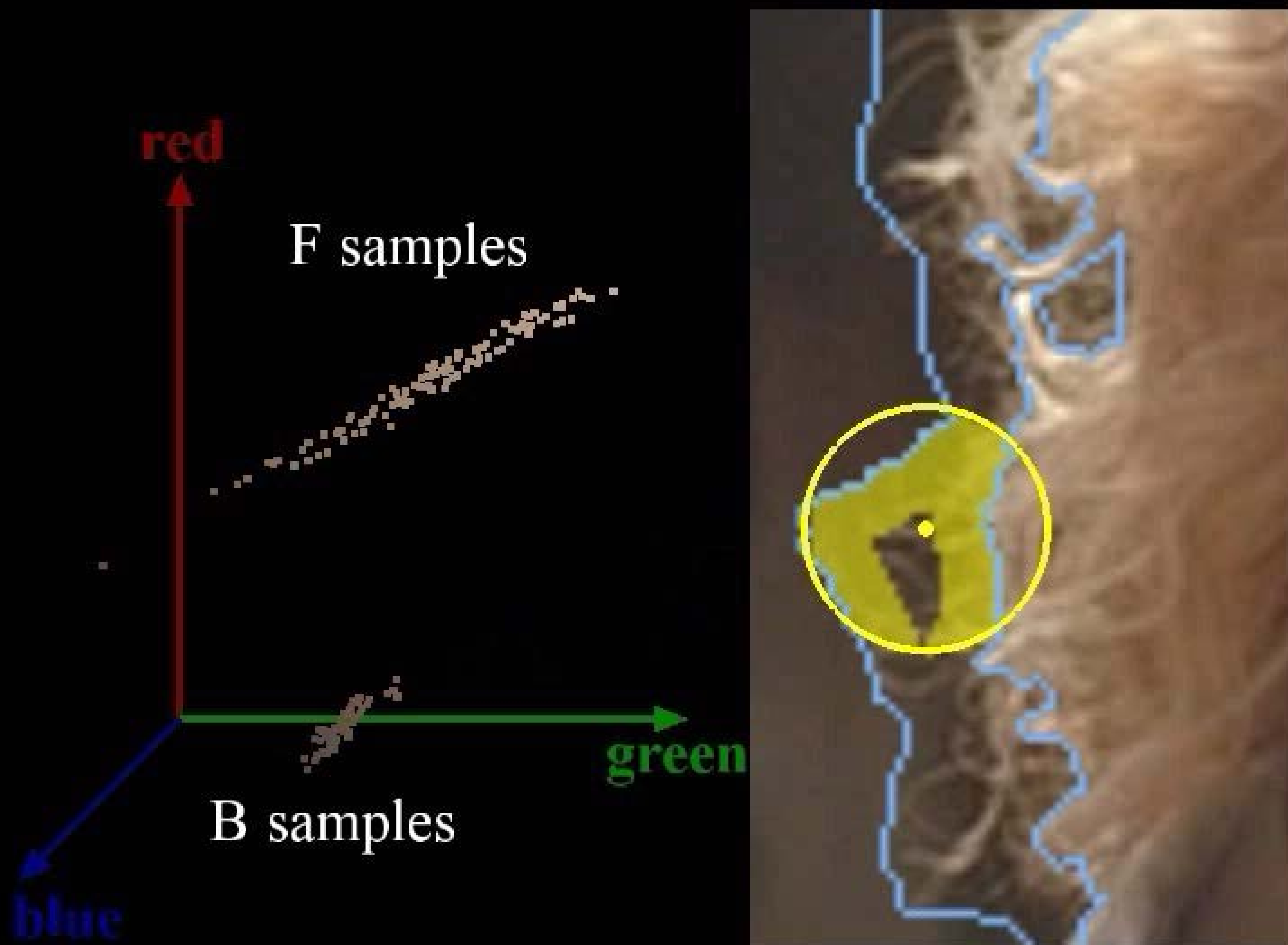
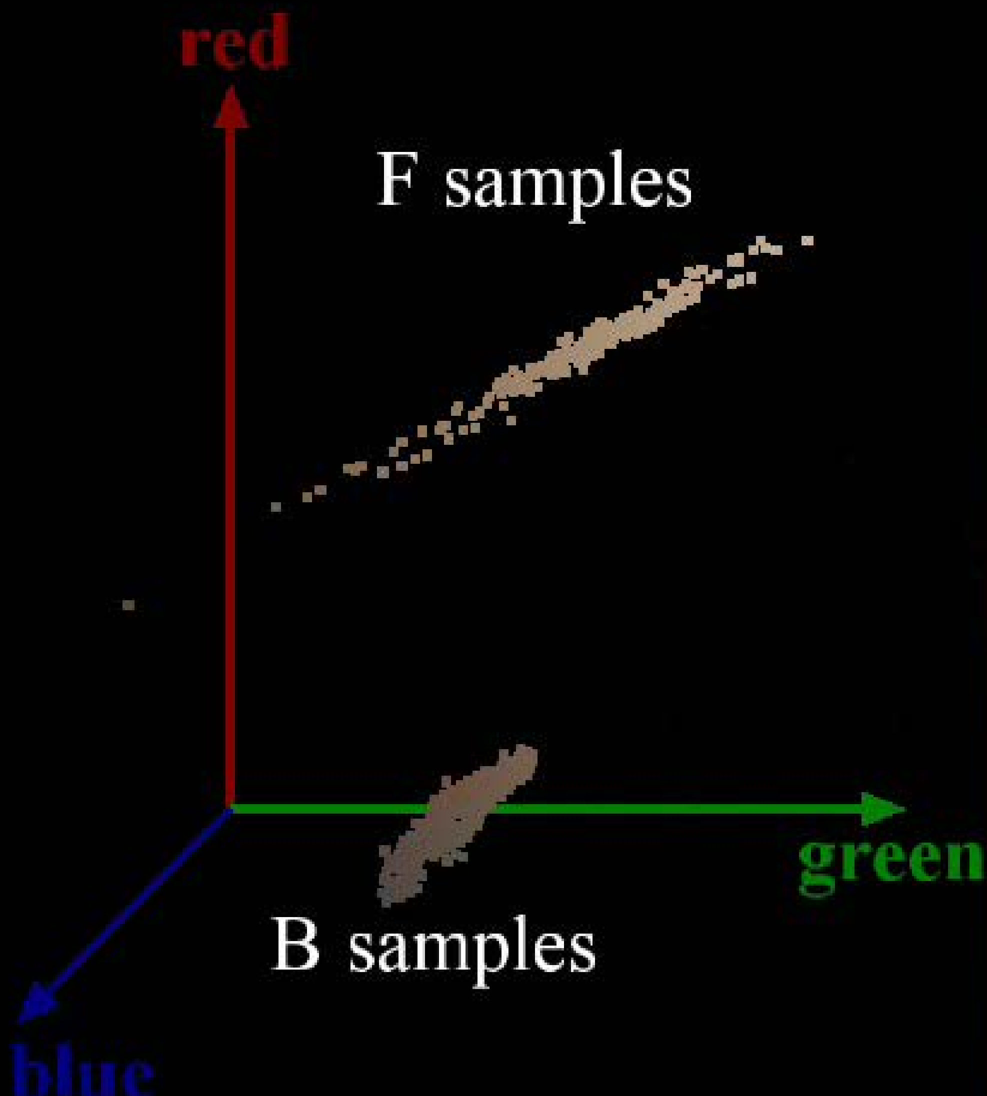
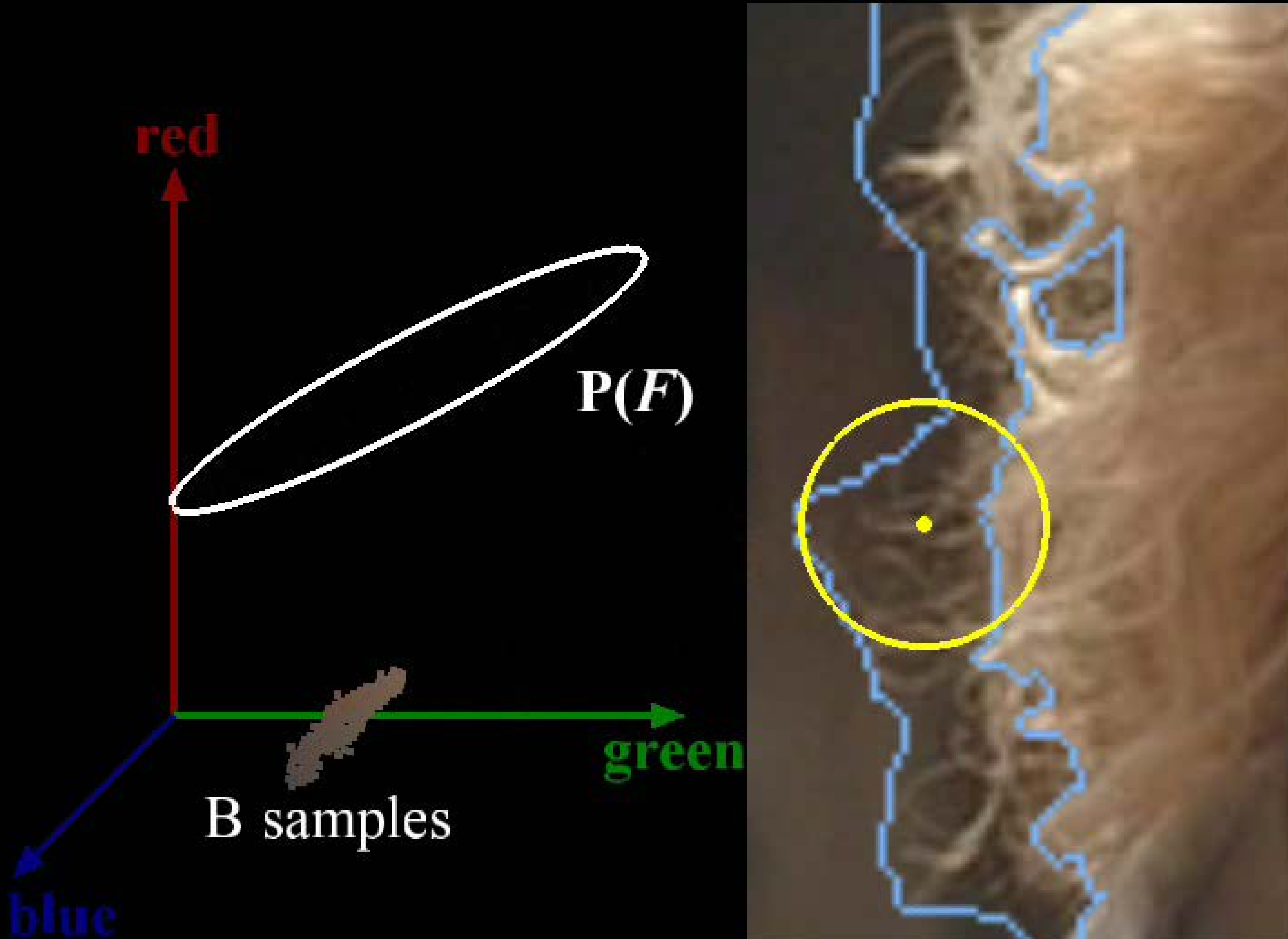


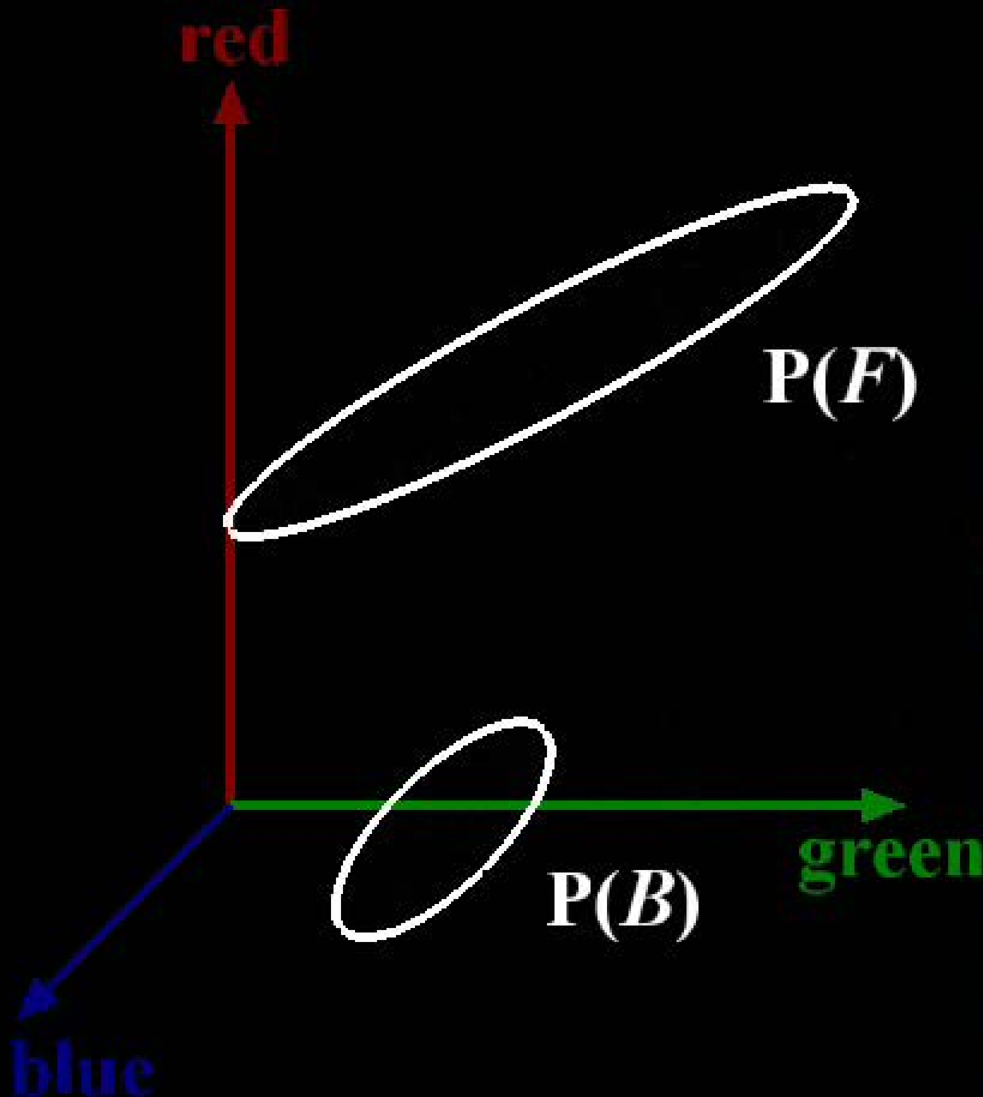
slides by Chuang *et al.*



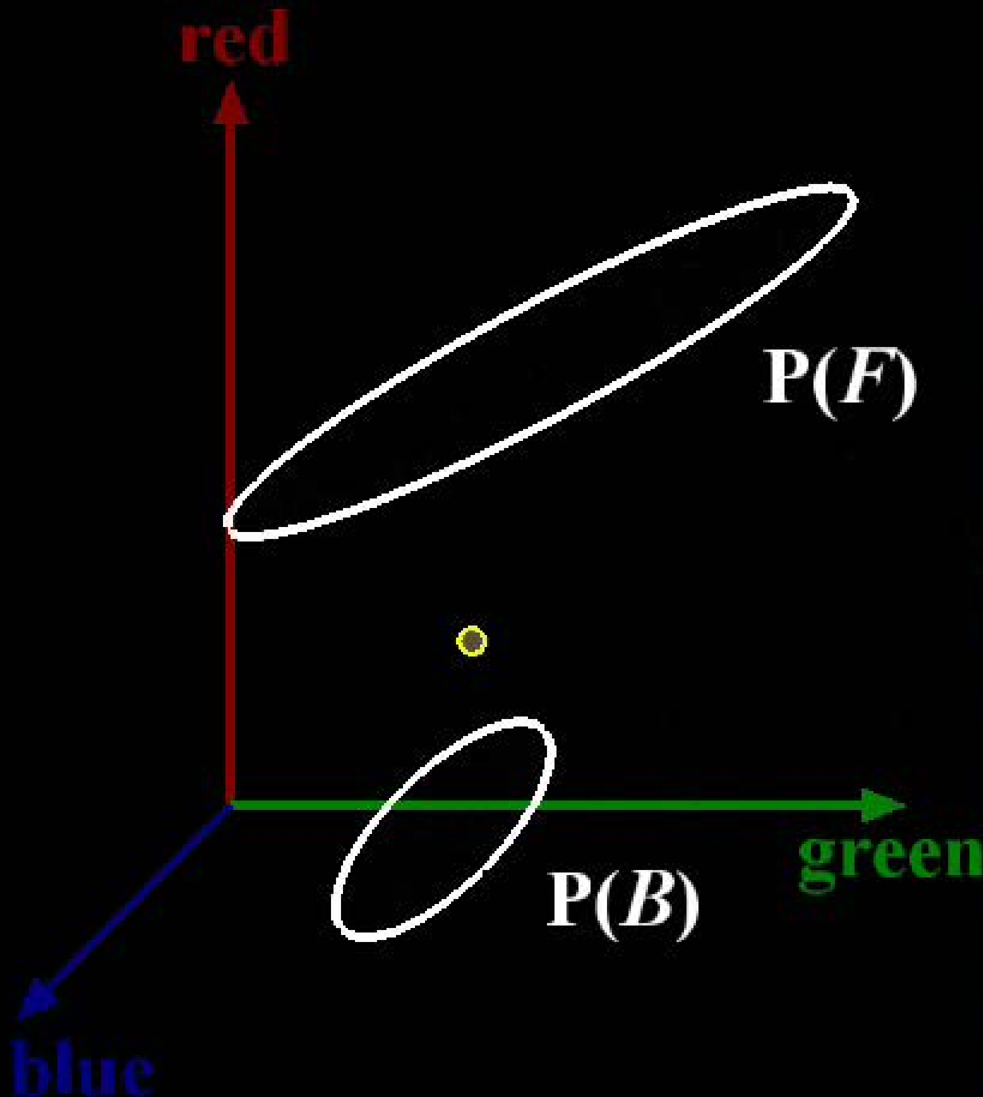
slides by Chuang *et al.*

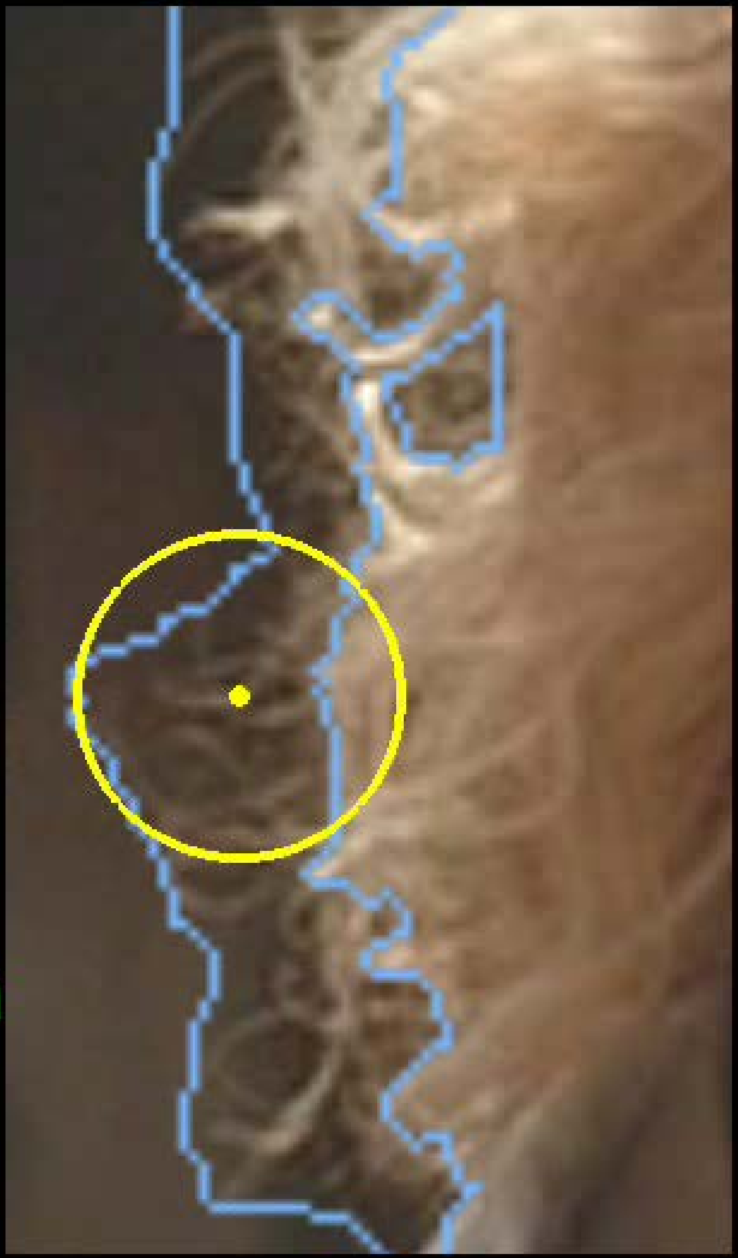


slides by Chuang *et al.*

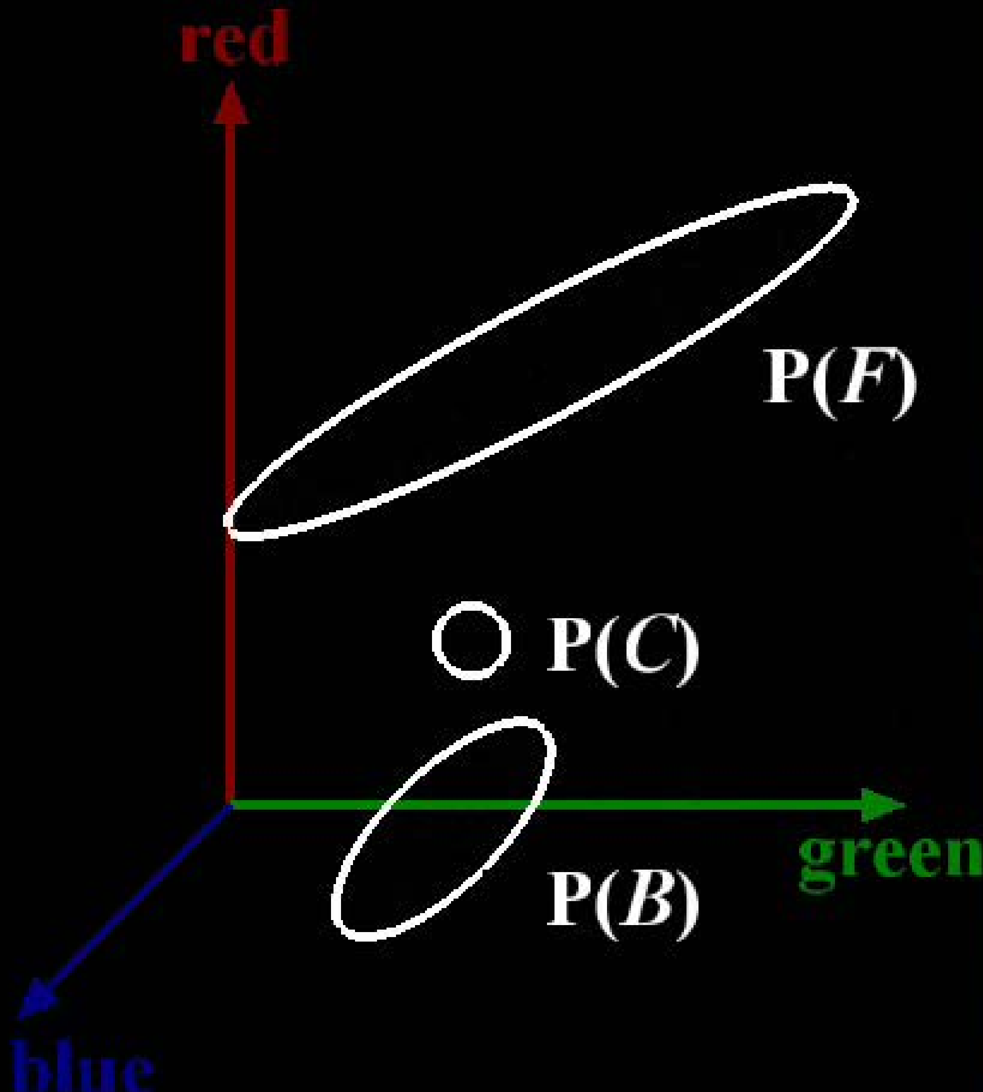


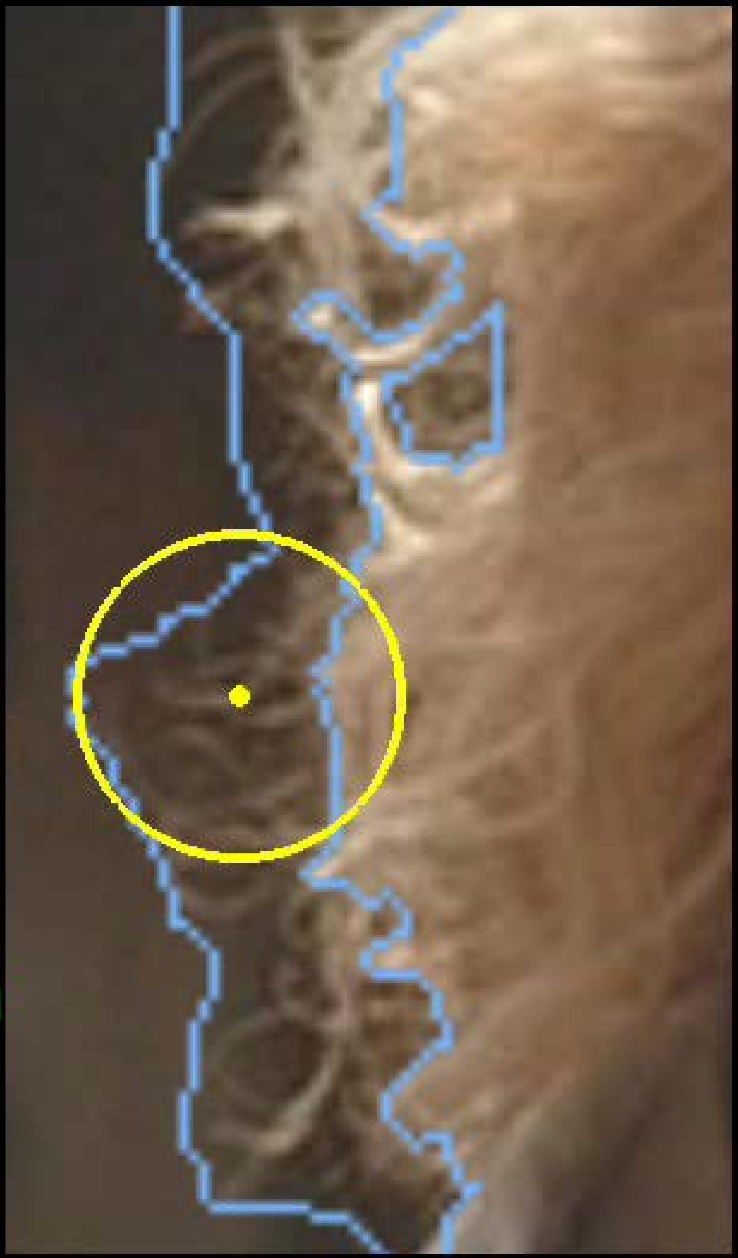
slides by Chuang *et al.*



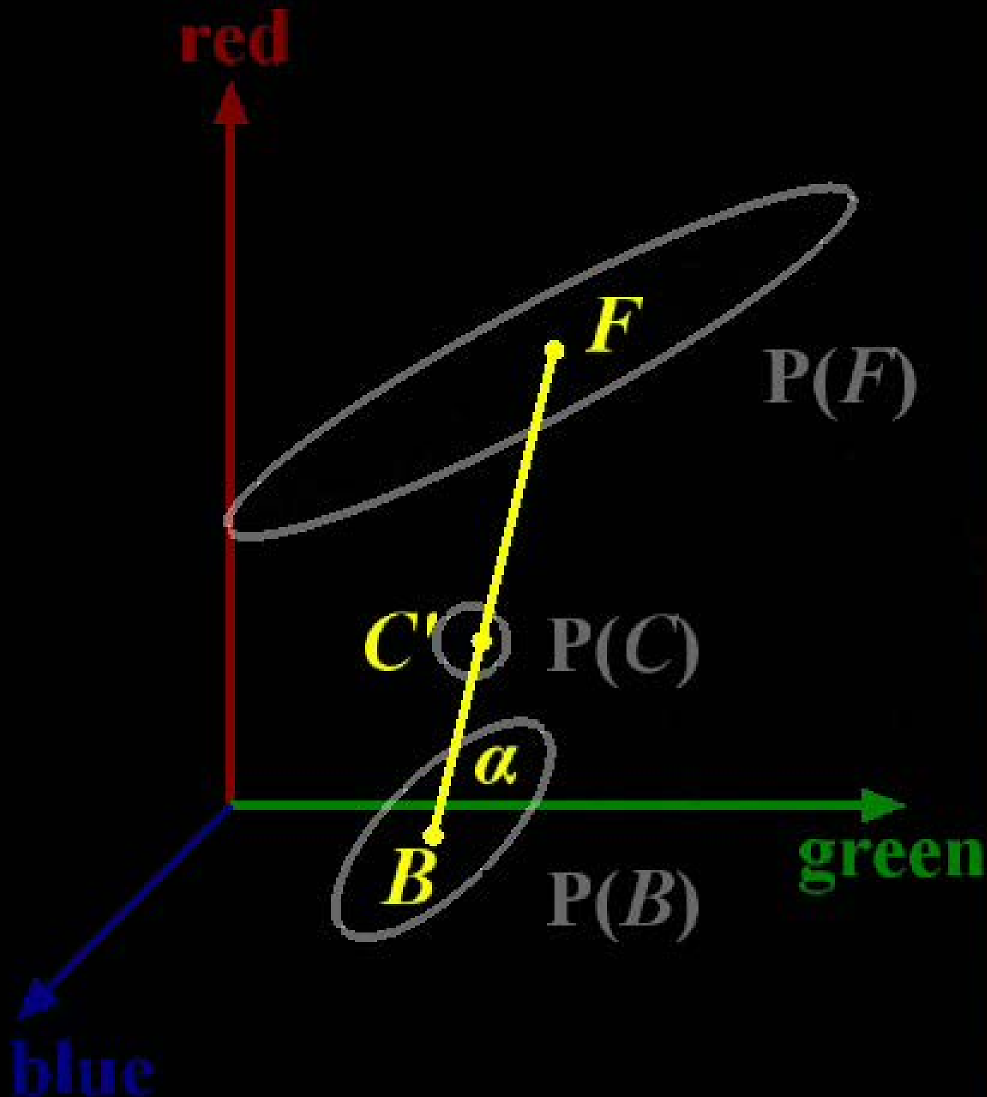


slides by Chuang *et al.*





slides by Chuang *et al.*



slides by Chuang *et al.*

Bayesian Framework

- Maximum *a posteriori* (MAP)

$$
\begin{aligned}
&\arg\max_{F,B,\alpha} P(F,B,\alpha|C) \\
&= \arg\max_{F,B,\alpha} P(C|F,B,\alpha)P(F)P(B)P(\alpha)/\underline{\underline{P(C)}} \\
&= \arg\max_{F,B,\alpha} \log P(C|F,B,\alpha) + \log P(F) + \log P(B) + \log P(\alpha)
\end{aligned}
$$

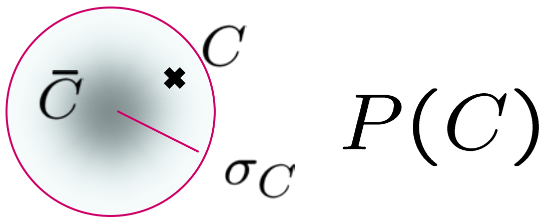
likelihood and priors

Log Likelihood

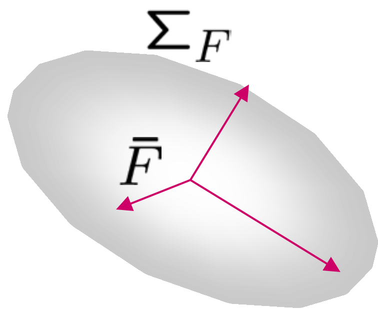
$$\bar{C} = \alpha F + (1 - \alpha) B$$

- Gaussian error

$$\log P(C|F, B, \alpha) = -\frac{1}{2\sigma_C^2} \|C - \alpha F - (1 - \alpha) B\|^2$$



Priors



$P(F)$

$$\log P(F) = -(F_i - \bar{F})^T \Sigma_F^{-1} (F_i - \bar{F})/2$$

contribution of a nearby pixel p_i:

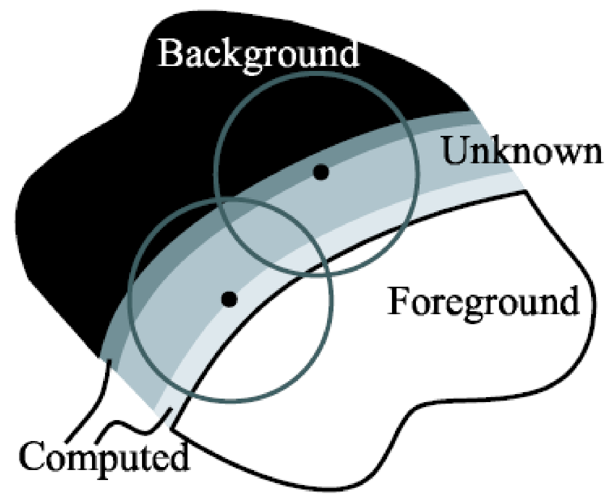
$$w_i = \alpha_i^2 g_i$$

$$\bar{F} = \frac{1}{W} \sum_{i \in \mathcal{N}} w_i F_i$$

$$\Sigma_F = \frac{1}{W} \sum_{i \in \mathcal{N}} w_i (F_i - \bar{F})(F_i - \bar{F})^T$$

$$W = \sum_{i \in \mathcal{N}} w_i$$

Bayesian



$P(B)$? $P(\alpha)$?

Optimization

- Iteratively solve for F and B with fixed alpha, and then solve for alpha with fixed F and B

$$\begin{aligned}&\arg\max_{F,B,\alpha} P(F,B,\alpha|C)\\&=\arg\max_{F,B,\alpha} \log P(C|F,B,\alpha)+\log P(F)+\log P(B)+\log P(\alpha)\end{aligned}$$

Alternate Optimization Scheme

Solve for F and B

- Taking the partial derivatives with respect to *F* and *B* and setting them equal to 0

$$\begin{bmatrix} \Sigma_F^{-1} + I\,\alpha^2/\sigma_C^2 & I\,\alpha(1-\alpha)/\sigma_C^2 \\ I\,\alpha(1-\alpha)/\sigma_C^2 & \Sigma_B^{-1} + I\,(1-\alpha)^2/\sigma_C^2 \end{bmatrix} \begin{bmatrix} F \\ B \end{bmatrix}$$

$$= \begin{bmatrix} \Sigma_F^{-1}\bar{F} + C\alpha/\sigma_C^2 \\ \Sigma_B^{-1}\bar{B} + C(1-\alpha)/\sigma_C^2 \end{bmatrix}$$

[6-by-6] [6-by-1] = [6-by-1]

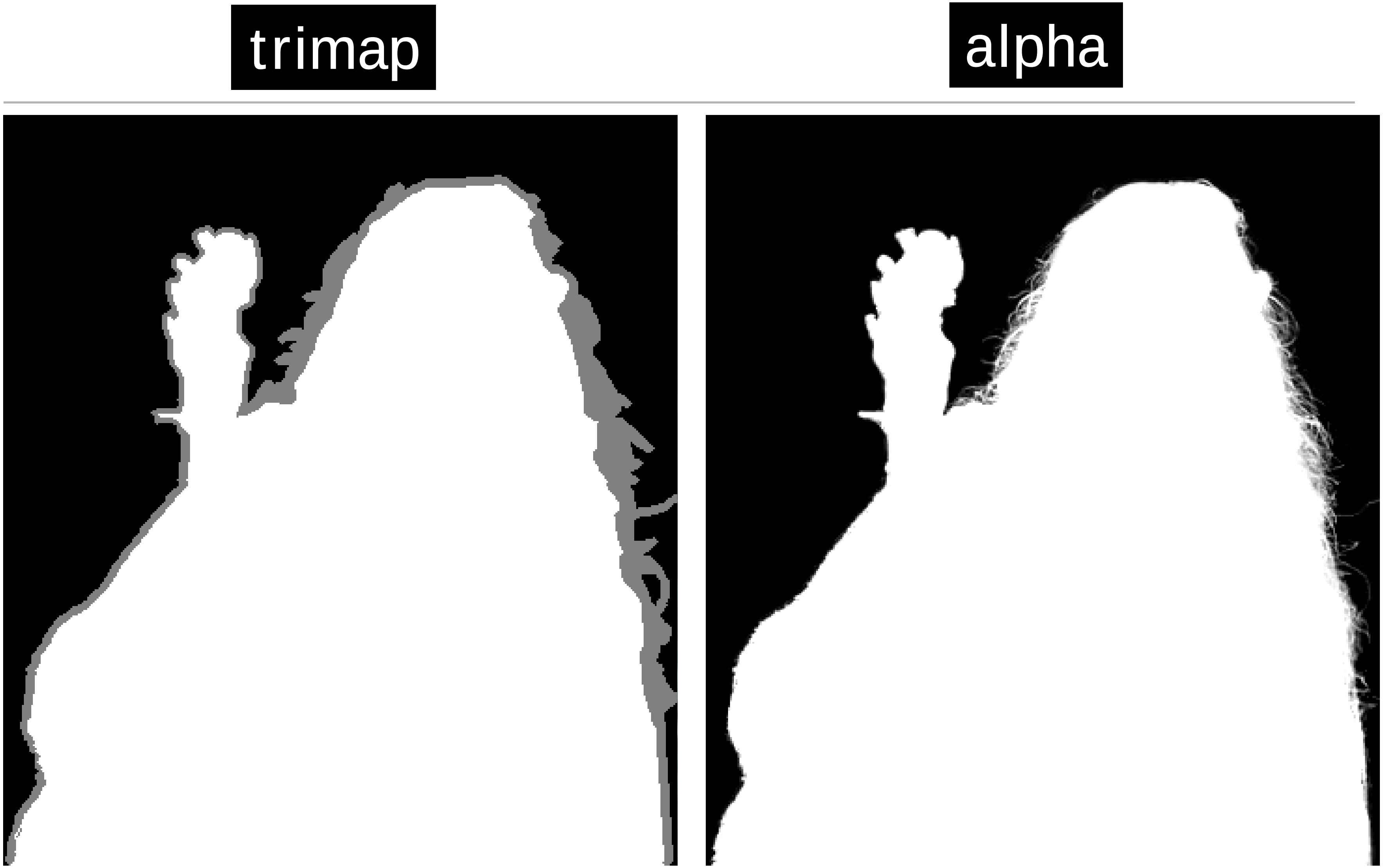
Solve for Alpha

- Projecting the observed color C onto the line segment FB in color space

$$\alpha = \frac{(C - B) \cdot (F - B)}{\|F - B\|^2}$$

taking the partial derivatives with respect to alpha
and setting it equal to 0

$$\arg\max_{F,B,\alpha} P(F, B, \alpha | C)$$
$$= \arg\max_{F,B,\alpha} \log P(C|F, B, \alpha) + \log P(F) + \log P(B) + \log P(\alpha)$$



Results

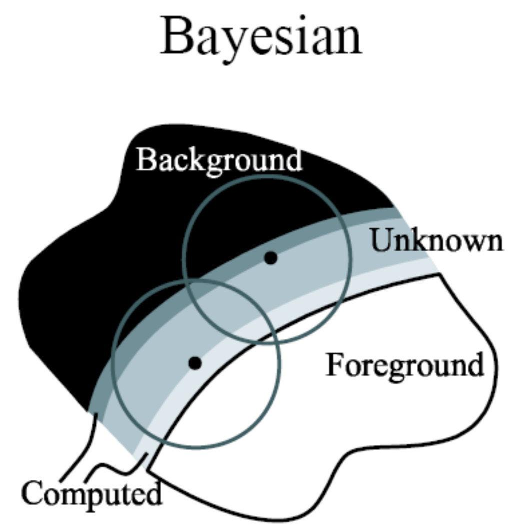
slides by Chuang *et al.*

Results

slides by Chuang *et al.*

Questions

- Color or grayscale?
- Time complexity?
  - Solving 6x6 linear equations
  - Computing covariance matrices



Flash Matting

I^f

I

$$
\begin{aligned}
I &= \alpha F + (1 - \alpha) B, \\
I^f &= \alpha F^f + (1 - \alpha) B^f
\end{aligned}
$$

Flash Model

point light source radiance

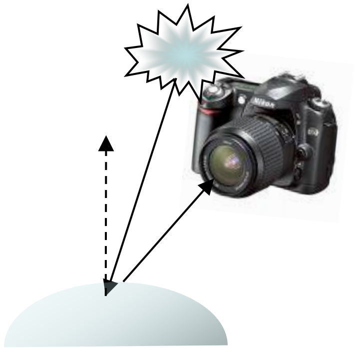
$$E = L \cdot \rho(\omega_i, \omega_o) \cdot r^{-2} \cdot \cos\theta$$

reflectivity

distance

angle between flash direction and surface normal

the flash intensity falls off quickly with distance r



Assumptions

- Only the appearance of the foreground is dramatically changed by the flash

- The input image pair is pixel aligned

$$B^f \approx B$$

$$\Downarrow$$

$$I^f = \alpha F^f + (1 - \alpha) B$$

Foreground Flash Matting

- Subtracting

$$I = \alpha F + (1-\alpha)B$$
$$I^f = \alpha F^f + (1-\alpha)B$$
$$\Downarrow$$
$$I' = I^f - I = \alpha(F^f - F) = \alpha F'$$

the *flash-only* image

I

I^f

Joint Bayesian Flash Matting

$$\arg\max_{\alpha,F,B,F'} \log P(\alpha, F, B, F'|I, I')$$
$$= \arg\max_{\alpha,F,B,F'} \log P(I|\alpha, F, B) + \log P(I'|\alpha, F')$$
$$+ \log P(F) + \log P(B) + \log P(F') + \log P(\alpha)$$

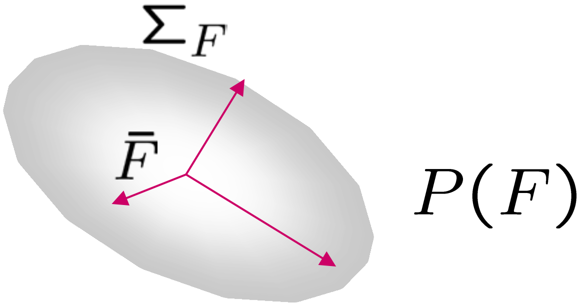
$$\log P(I|\alpha, F, B) = -\frac{1}{2\sigma_I^2} \|I - \alpha F - (1-\alpha)B\|^2$$?

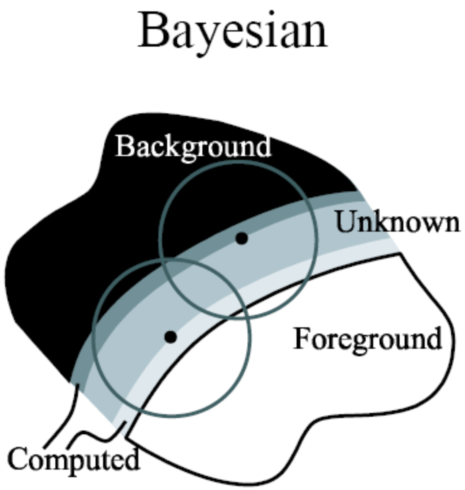
$$\log P(I'|\alpha, F') = -\frac{1}{2\sigma_{I'}^2} \left\|I' - \alpha F'\right\|^2$$

Priors

$$\log P(F) = -(F_i - \bar{F})^T \Sigma_F^{-1} (F_i - \bar{F})/2$$

$$\log P(F') = -(F'_i - \bar{F}')^T \Sigma_{F'}^{-1} (F'_i - \bar{F}')/2$$





Optimization

- Iteratively and alternately

$$\begin{bmatrix} \Sigma_F^{-1} + \mathbf{I}\alpha^2/\sigma_I^2 & \mathbf{I}\alpha(1-\alpha)\sigma_I^2 & \mathbf{0} \\ \mathbf{I}\alpha(1-\alpha)\sigma_I^2 & \Sigma_B^{-1} + \mathbf{I}\alpha^2/\sigma_I^2 & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \Sigma_{F'}^{-1} + \mathbf{I}\alpha^2/\sigma_{I'}^2 \end{bmatrix} \begin{bmatrix} F \\ B \\ F' \end{bmatrix}$$

$$= \begin{bmatrix} \Sigma_F^{-1}\overline{F} + I\alpha/\sigma_I^2 \\ \Sigma_B^{-1}\overline{B} + I(1-\alpha)/\sigma_I^2 \\ \Sigma_{F'}^{-1}\overline{F'} + I'\alpha/\sigma_{I'}^2 \end{bmatrix}$$

$$\alpha = \frac{\sigma_{I'}^2 (F-B)^T (I-B) + \sigma_I^2 F'^T I'}{\sigma_{I'}^2 (F-B)^T (F-B) + \sigma_I^2 F'^T F'}$$

"Joint" Bayesian

$$\alpha = \frac{\sigma_{I'}^2 (F-B)^T (I-B) + \sigma_I^2 F'^T I'}{\sigma_{I'}^2 (F-B)^T (F-B) + \sigma_I^2 F'^T F'}$$

$$F' \approx 0 \quad \Rightarrow \quad \alpha \approx (F-B)^T (I-B) / (F-B)^T (F-B)$$

[Chuang *et al.*]

$$F \approx B \quad \Rightarrow \quad \alpha \approx F'^T I' / F'^T F'$$

Results